*Volume 34* April, 1948 *Number 4*

# Lubrication

## A Technical Publication Devoted to the Selection and Use of Lubricants

THIS ISSUE

Aircraft Gas Turbine
Fuels and Lubricants

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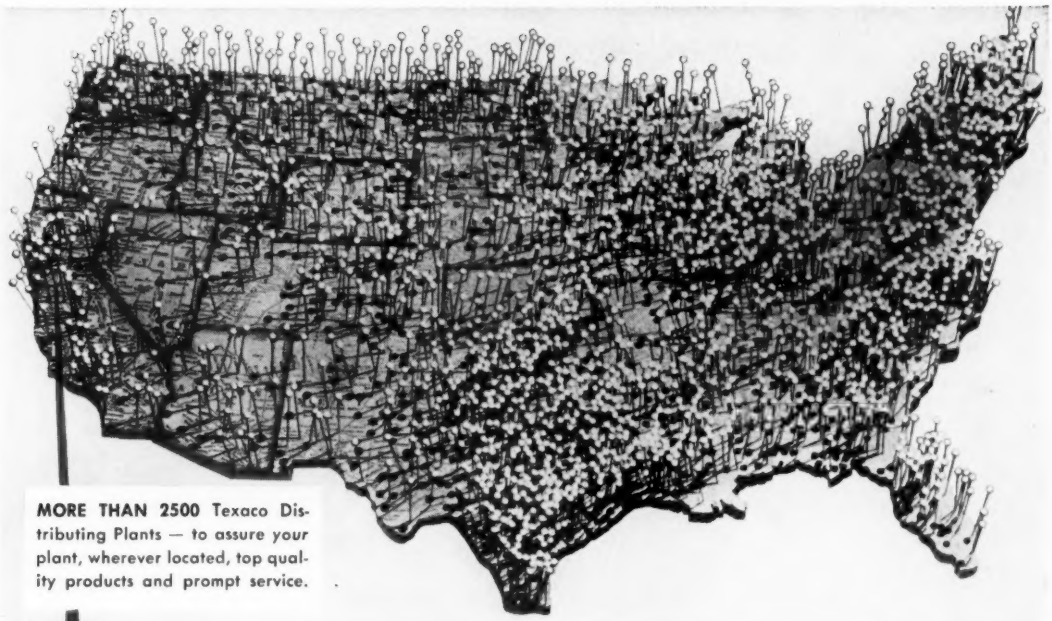

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# LUBRICATION

A TECHNICAL PUBLICATION DEVOTED TO THE SELECTION AND USE OF LUBRICANTS

Published by
The Texas Company, 135 East 42nd Street, New York 17, N. Y.
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Vol. XXXIV April, 1948 No. 4

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# Aircraft Gas Turbine Fuels and Lubricants

SINCE the first flight of the Wright Brothers no other aviation development has attracted as much public imagination as the jet propulsion aircraft gas turbine. Within a comparatively short period this radically new type of power plant has already surpassed its piston engine contemporary in many respects. With its widespread use in military aircraft came an entirely new set of speed and performance records. Because these engines are in their infancy and undergoing such a rapid rate of development, the fuel requirements for economy, power and range as related to engine design are being actively investigated.

The petroleum industry has at hand a wealth of experience and know-how in fuel manufacture which is proving of great value to designers. This discussion is based upon information obtained on fuel requirements of existing engines. Inasmuch as turbine performance depends upon matching engine design with fuel properties the present factors may be expected to change with the evolution of new designs.

The problem of lubrication of the aircraft gas turbine, on the other hand, may be more clearly defined. Those parts requiring lubrication are somewhat similar to the ones found in piston engines. The conditions of speeds, loads and operating temperatures are however quite different.

## HOW IT WORKS

The aircraft gas turbine consists of three basic components: (Figure 1).

1. An air compressor (centrifugal or axial).
2. A series of combustion chambers, either the "can" or annular type.
3. A turbine whose shaft is connected to the compressor.

The compressor compresses air to approximately four atmospheres. At high air speeds the ramming effect due to speed of the plane may add another atmosphere of pressure. From the compressor, air enters the combustion chamber or chambers where it is mixed with fuel and combustion takes place. Fuel is sprayed in a continuous stream from fuel nozzles under high pressure. Mixing with a portion of the air, it burns continuously, and subsequently mixes with the remainder of the air to reduce the temperature to a level permitted by available materials. The overall air fuel ratio averages about 60:1. The hot gases at about 1500°F. after leaving the combustion chambers, next pass through nozzle guide vanes and finally pass the turbine blades.

In the turbojet engine the turbine takes out just enough energy from the hot gases to operate the compressor and accessories and the balance is utilized to create a high gas velocity from the tail cone.

The temperature of gases leaving the tail cone is usually around 1100°F. and the velocity is about 1200 miles per hour. The amount of power required by the compressor is considerable, however. For a jet engine producing 4000 pound thrust the compressor requires about 8000 HP.

In the propjet engine a larger proportion of energy is converted into mechanical power, some of which is transmitted from the turbine to a propeller through reduction gears.



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It is interesting to note that the propulsion principle of both propeller and jet are similar. In each case the forward thrust is developed from a reaction to accelerating a mass of air to the rear. In a propeller drive a large mass of air within the propeller arc is accelerated a moderate amount. In the turbojet engine a moderate mass of air is accelerated a large amount.

## GAS TURBINE FUELS

The properties which are desired in a turbine fuel may be listed below:

1. Volatility should be selected on the basis of starting, safety, combustion, smoke, deposits, and availability.
2. Vapor pressure involves considerations of vapor handling capacity of a given fuel system and fuel evaporation.
3. Composition should provide proper combustion and rapid burning.
4. Heating value — the highest heating value is desired provided it is not at the expense of other factors.
5. Stability or gum tests will be required according to length and conditions of storage.
6. Freezing point lower than minimum anticipated atmospheric temperature.

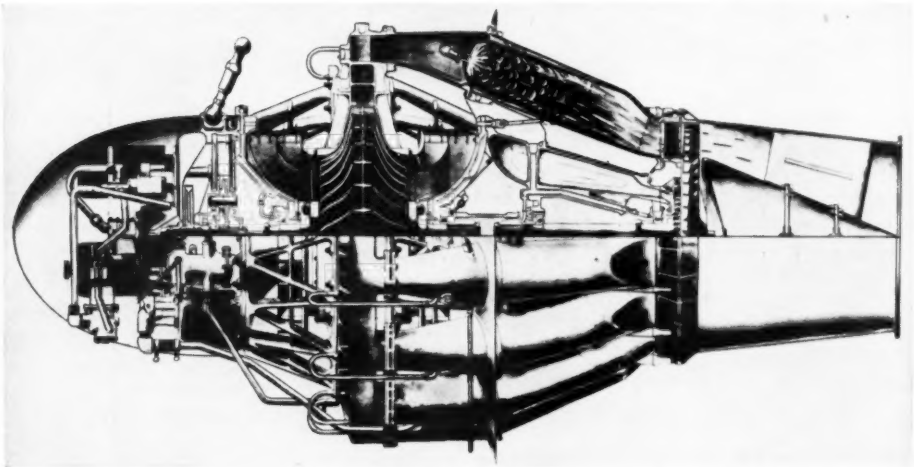
### Volatility

Volatility is one of the most important physical properties of jet fuels. It is important because of its effect upon starting, combustion efficiency, engine deposits, evaporation losses, vapor locking, fire hazard, and even availability.

High rates of climb and high altitude operation may be responsible for some appreciable losses of fuel from evaporation. A comparison between evaporation losses of aviation gasoline and a low volatility fuel is shown on Figure 2. Starting with a fuel temperature of 100°F. in a tank at the time of take-off, it is apparent that appreciable losses may occur with aviation gasoline upon reaching altitudes in excess of 20,000 feet — whereas the losses from a less volatile fuel are insignificant up to 55,000 feet.

Vapor locking tendencies of aviation gasoline at various altitudes are compared with those of low volatility fuel (Figure 3). Aviation gasoline will require fuel booster pumps to prevent vapor locking; whereas these pumps have not been found necessary when using a low volatility fuel. If a fuel system has a vapor-liquid volume ratio of 2 and a fuel temperature of 100°F., it is apparent that with aviation gasoline booster pumps will have to be operated before reaching an altitude of 15,000 feet to prevent vapor locking; whereas the same system would not require booster pumps up to 55,000 feet with a low volatility fuel.

While a volatile fuel such as aviation gasoline has some disadvantages with respect to evaporation losses and vapor locking, it has some distinct advantages during low temperature starting and combustion efficiency. The tolerance permitted in the front end volatility varies widely from one engine to another and no general conclusions can be reached at this time. However, a certain amount of general information is available on a few of the more popular designs of jet engines which may be of interest.



*Courtesy General Electric Company*

**Figure 1 — Cut away view of J-33 turbojet engine (GE Model I-40) designed and developed originally by the General Electric Company and subsequently built in quantity by the Allison Division of GMC. This turbojet engine has a double entry centrifugal compressor, 14 "can" type combustion chambers and a single stage turbine. Static thrust 4,000 pounds at 11,500 rpm under standard sea level conditions with zero ram.**

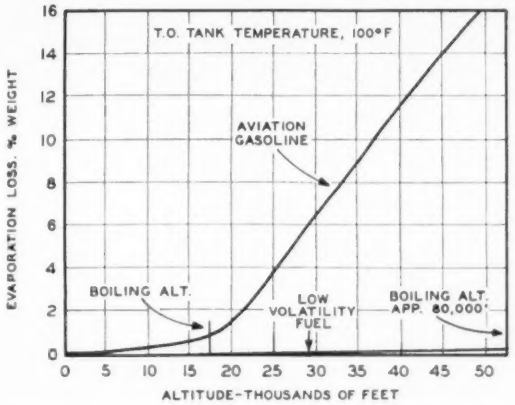



Figure 2 — Comparison of evaporation losses of aviation gasoline and low volatility fuel from aircraft fuel tanks at moderate rates of climb (reference a).

Aviation gasoline with an ASTM distillation 10% point of 160°F. permits easy starting at temperatures down to −65°F. In the same type of engine, starting may be difficult at temperatures around −40°F. with a fuel having a 10% point of 300 to 380°F.

During the starting period of a turbo engine richer mixtures are employed — a procedure which is similar to the piston engine. If the start of combustion is delayed, as it might be with a low volatility type of fuel, the whole interior of the turbine engine may become drenched with unburned fuel which is apt to burn off suddenly once combustion has started, causing overheating or a "hot start". While "hot starts" can be reduced through changes in engine design and starting technique, they, nevertheless, depend upon fuel volatility. "Hot starts" are bad for the engine because of the overheating and subsequent damage to engine parts.

While some of the leading models of jet engines have been designed for satisfactory operation on either a low volatility fuel, such as kerosine or even gasoline, a few brief tests were conducted with heavier fuels to find out what might happen in regard to starting, combustion efficiency and deposits. The tests with the heavier fuels, Nos. 64, 65, 66, and 67 (Figure 4), were run on one model of full scale jet engine. The tests on this one engine are somewhat limited and not to be construed as applicable to other models of jet engines. With gas oil No. 64 (B.P. 464-688°F.) starting was impossible at room temperature; although the engine would operate fairly well under cruising conditions at sea level if started on kerosine and switched over to this fuel. Combustion was poor under both idling conditions and rated speeds.

With a heavier gas oil, No. 65 (B.P. 475-724°F.+) starting was impossible and the engine would not operate under any conditions. The next heavy fuel tested was a gas oil-distillate blend, No. 66, having a much lower front end (B.P. 362-715°F.) and this fuel started satisfactorily at room temperatures and permitted normal operation in the cruising range; although performance of the engine was not very good at idling and rated speeds.

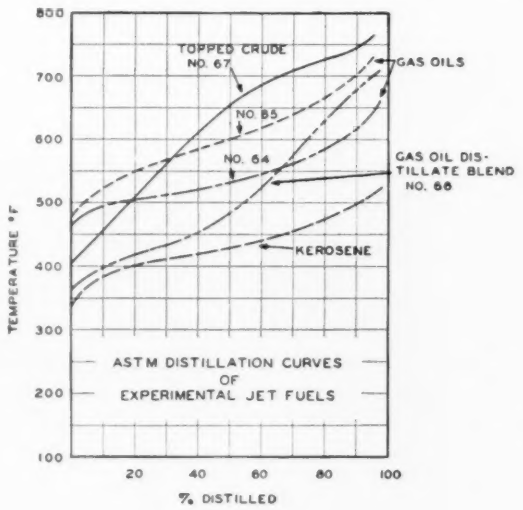



Figure 4

The heaviest fuel tested was a topped crude, No. 67 (B.P. 405-750°F.+). It was necessary to start the engine with kerosine and then switch over to this fuel and poor operation was observed throughout the entire speed range under sea level conditions. The burning characteristics of this fuel were so slow that the flame extended down through the turbine disc and into the tail cone assembly causing overheating and damage to these parts. Although the engine used in these tests was designed to utilize kerosine, it is interesting to note what may be expected with some of the heavier gas oils.

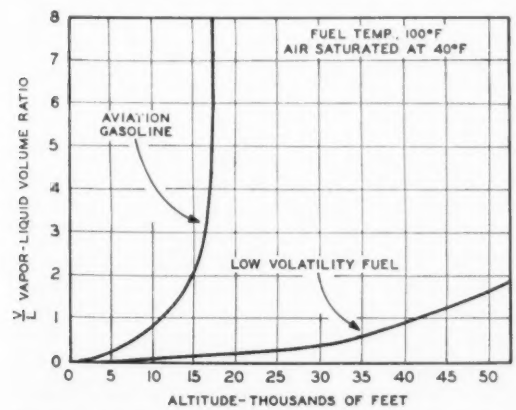



Figure 3 — Comparative vapor formation of aviation gasoline and low volatility fuel in a typical aircraft fuel system at various altitudes (reference a).



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## Fire Hazard

Commercial operators believe that the turbo engine has advantages over the piston engine in its ability to use a less volatile fuel and thereby reduce some of the fire hazards. It should be pointed out that any fuel which will burn in an engine will also burn outside under the right set of conditions and

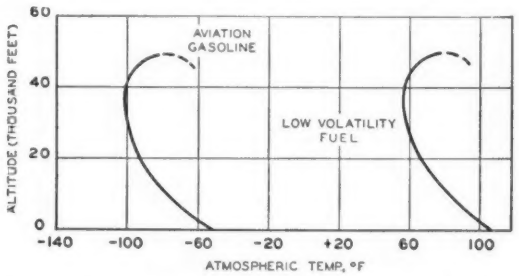



**Figure 5 — The effect of altitude and temperature on the explosive limits of aviation gasoline and low volatility fuel in a partly filled fuel tank under equilibrium conditions.**

A comparison between the explosive limits of aviation gasoline and low volatility fuel appear on Figure 5. These data were obtained from actual laboratory tests using a hot wire as an ignition source in the vapor space. The solid line in these curves indicates the lean limit and the broken line, which only partly completes the envelope, the rich limit of explosion. From these data, it appears that explosive conditions in the vapor space may be found with a low volatility fuel under extremely hot weather conditions and also with aviation gasoline under extremely low temperature conditions. Considering the wide variety of temperatures and altitudes under which aircraft operate today, the relative explosion hazards of both fuels are approximately the same. The use of an inert gas such as $CO_2$ or nitrogen has been proposed for the purpose of blanketing fuels if it is found necessary to prevent an explosive mixture from forming.

A test program recently conducted to investigate the inflammability of various fuels furnishes some

**Figure 6 — A laboratory fire test stage used to investigate the inflammability of various fuels and oils under different conditions. This shows a typical fire following crashing of samples of aviation gasoline 15 feet away from a lighted flare.**

since no fuel can be regarded as absolutely fireproof, the term safety fuel is a misnomer. At the same time there appear to be some important differences between the inflammability of different fuels under certain conditions which will be discussed below.

The three types of fire hazards involving aviation fuels are as follows:

a. Explosion of the vapors in the fuel tank.
b. Spontaneous ignition from contact with a hot surface.
c. Fires arising from spilled or crashed fuel covering the airplane or the ground.

interesting information on parts (b) and (c). The test equipment (Figure 6) consisted of a fire stage with a concrete platform 6′ x 24′, a 9′ backwall and a large blower at one end to furnish winds up to 25 mph. Over a thousand tests were made utilizing fuels and oils of widely different distillation ranges and compositions. These samples of fuels and oils were crashed in bottles or spilled from containers from different heights. The sources of ignition employed were hot pipe, hot wire, spark and flare, and atmospheric conditions included all sorts of winter and summer weather.

Approximately 50 hot pipe ignition temperature

tests were run on samples of fuel and oil with the following results:

| | Hot pipe ignition temperature °F, ± 100° F |
|---|---|
| Aviation Gasoline 100/130 | 1250 |
| Low Volatility Fuel (300-400°F) | 1250 |
| Aircraft Engine Oil 120 | 1000 |

From these tests it appears that aircraft engine oil 120 had a slightly lower hot pipe ignition temperature. This may be partly caused by the fact that such an oil, being non-volatile, remained on the hot pipe for a longer period of time. Both fuel samples boiled away before reaching the temperature of the hot pipe, making it difficult to interpret these results as self-ignition temperature. When the temperature of the hot pipe was high enough to ignite all three samples, the fuel burned more violently and fire spread instantly. Oil fires on the other hand were more confined and spread very slowly if at all.

The effect of volatility on inflammability is illustrated in Figure 7. This figure shows the borderline condition between fire and no-fire regions under various sources of ignition, wind velocities and methods of crashing or spilling samples. The worst condition found was spilling fuel from a 2 ft. height into a lighted flare in the presence of a 15 mph wind. Under these conditions the borderline volatility between fire and no-fire regions was an ASTM 10% distillation point minus an atmospheric temperature of 250° F. In other words, at 100° F. atmospheric temperature a fuel having a 10% point of 350° F. would be borderline with respect to inflammability under these conditions.

The effect of either distance or wind velocity is relatively minor for flame distances in the range of one to five feet. At these conditions ignition appears to result from spray contacting the flame. At the eight foot flame distance, vapor flash ignition occurs for fire runs made with wind velocities up to 10 mph. Above that velocity spray flash becomes the major cause of ignition for fire runs.

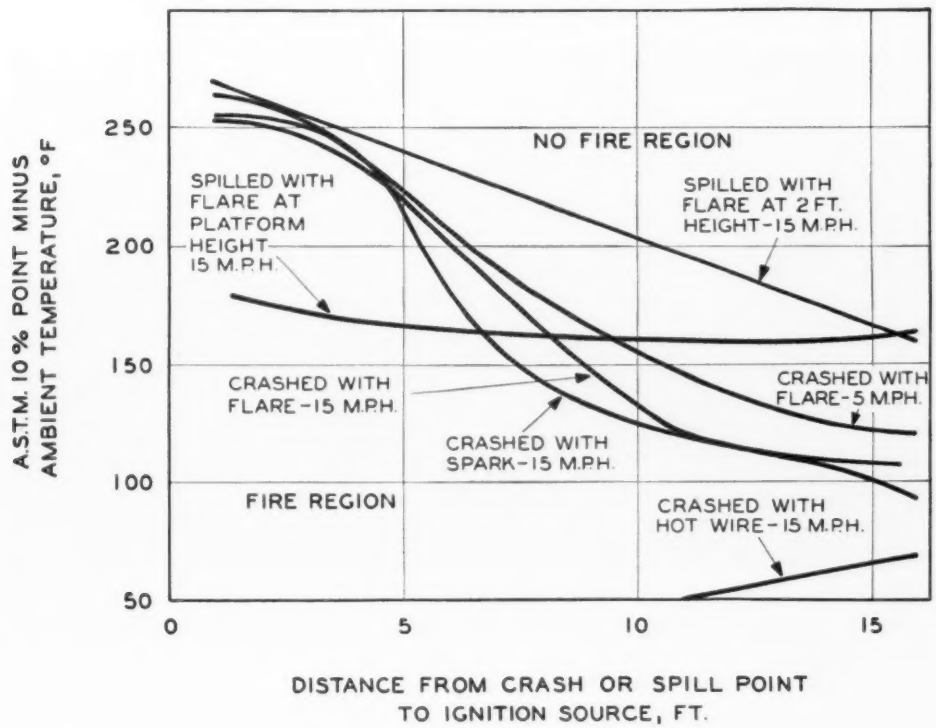



Figure 7 — The effect of volatility and source of ignition on inflammability of various types of fuels.

Some tests were also run with precooled fuels at temperatures 15 and 30° F. below ambient temperatures. Within the limits of these tests precooling had no appreciable effect on the borderline volatility for occurrence of fire.

Platform conditions were also varied to include water, rain and snow. With a wet platform results were about the same as when dry. When tests were conducted in the rain, fuels strangely enough were

more likely to ignite than in dry weather by an amount equivalent to raising the borderline volatility curve by approximately 25° F.

It should be brought out at this time that there are no concrete data, based upon experience, of relative fire hazards of various fuels in aircraft. There is no operational experience available of a number of identical aircraft where part of the group used a volatile fuel such as aviation gasoline and the other a low volatility fuel such as kerosine. Some attempts have been made to compare relative fire hazards of one model of aircraft using gasoline with another model of an entirely different design and engine using a low volatility type of fuel. However, it is impossible to draw any conclusions from these examples due to the number of variables involved.

*Courtesy Boeing Airplane Company*

**Figure 8 — First flight photograph of Boeing "Stratojet" XB-47 jet bomber. This ultra high speed bomber is powered with 6 General Electric J-35 (TG-180) jet engines. The world's first bomber to feature sharply swept back wing and tail surfaces.**

## Composition

From the limited amount of information available, it appears that fuel composition has some effect upon combustion efficiency, smoke and deposits. Some of the more popular models of jet engines do not appear to be particularly sensitive in this respect. However, since engine design plays such an important part on the performance of fuels, any data obtained in one model of engine does not necessarily apply to another and, therefore, it is impossible to make any general conclusions at this time.

In two well-known models of jet engines, both paraffinic and naphthenic straight run fuels are easier to burn than a highly aromatic type made from cracked stocks. For example, of three fuels with identical distillation range, similar to kerosine, but of different composition, paraffinic and naphthenic fuels gave good combustion efficiency and freedom from smoke or deposits at various altitudes up to 40,000 feet. The aromatic fuel, containing approximately 50% aromatics, was more difficult to burn and gave some smoking and rather objectionable deposits under sea level conditions after a short period of testing.

The general feeling is that fuels containing aromatics up to 30% may be satisfactory although much more data are necessary before any general conclusions can be reached. A great deal of information is needed studying the behavior of aromatic fuels of different distillation ranges. The behavior of olefins also must be carefully investigated before we will know whether cracked fuels may be successfully used in the turbo engine.

## Heating Value

The principal disadvantage of the turbo engine compared with the piston engine is its higher fuel consumption. Since heating value of the fuel directly affects the range of aircraft, it is desirable to select a fuel of the highest heating value. Since the latest models of aircraft are becoming volume limited — i.e. less space is available for fuel tanks as a result of thinner wings, higher wing loading and smaller fuselage — it appears that selecting a fuel of the highest B.T.U. per gallon is desirable.

**TABLE 1**

GUM STUDY OF VARIOUS STRAIGHT RUN AND CRACKED FUELS FOR PROPOSED JP-3 SPECIFICATION

| | | 100% STRAIGHT RUN | | | | | CRACKED-STRAIGHT RUN BLENDS | | |
|---|---|---|---|---|---|---|---|---|---|
| | | FUEL NOS. | | | | | FUEL NOS. | | |
| | Proposed JP-3 | 73 | 74 | 84 | 85 | 86 | 75 | 76 | 77 |
| Air Jet Residue | 10.0 | 4, 4 | 3, 3 | 4 | 3 | 15 | 17, 20 | 50 | 51 |
| Accel. Gum ( 7 hr.) | .. | 3, 3 | 4, 3 | .. | 11 | 18 | 125 | .. | 140 |
| Accel. Gum (16 hr.) | 20.0 | 3, 5 | 8 | 2 | 7 | 22 | 851 | 97 | 360 |
| Distillation, ASTM, Temp. °F EP | 600 | 565 | 550 | 566 | 583 | 587 | 554 | 570 | 600 |

A comparison between B.T.U. per gallon of aviation gasoline and three heavier fuels in the kerosine distillation range is given below.

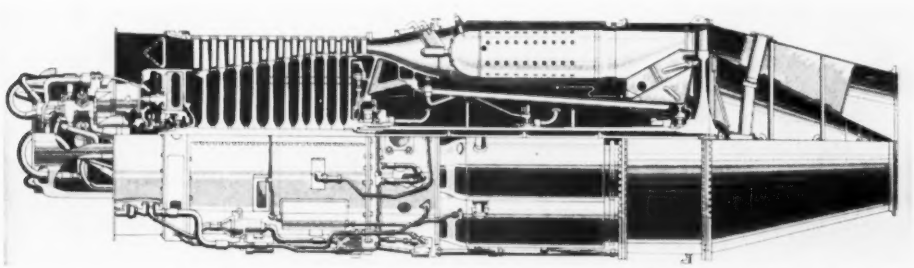
| | B.T.U./gal. | % Increase Compared Aviation Gasoline |
|---|---|---|
| Aviation Gasoline 100/130 | 114,000 | |
| Kerosine Distillation Range | | |
| Paraffinic | 126,700 | 11 |
| Naphthenic | 130,000 | 14 |
| Aromatic | 134,000 | 17.5 |

It is apparent that fuels of higher boiling point have greater heating values per gallon than aviation gasoline and also that aromatic type of fuels have greater heating value per gallon than either paraffinic and naphthenic fuels. Actual service tests between kerosine and aviation gasoline in a certain jet powered aircraft has demonstrated that improvement in range is almost in direct proportion to the heating value. On the basis of increasing the range, it might be advisable to have engines designed to utilize aromatic type of fuels with higher boiling points if possible.

## Stability

Some preliminary gum studies indicate that the present methods for gum tests are not too well suited to fuels with boiling points up to 600° F. maximum. Not only does it appear that different methods may be necessary but a different set of permissible gum values may be desirable as well. The methods for gum tests in their present form may exclude the use of any appreciable quantity of cracked stocks and thereby restrict the amount of satisfactory jet fuels which can be made available. In Table I is given a resume of some of these gum studies showing a comparison between proposed JP-3 grade fuels made from straight run stocks and straight run cracked blends. Five straight run fuels, Nos. 73, 74, 84, 85 and 86 were prepared from a wide variety of crude sources. With one exception these fuels met the residue and accelerated gum tests indicating that such fuels do not present much of a problem in this respect.

Three blends of cracked fuels, Nos. 75, 76 and 77 showed very high residue and accelerated gum values. Even if such fuels were inhibited for satisfactory storage, it is doubtful whether they would pass the present gum tests. Long-time storage tests



*Courtesy General Electric Company*

**Figure 9 — A cut away of J-35 General Electric TG-180 turbojet engine showing axial flow compressor, combustion chamber and turbine. Static thrust is 4,100 pounds at sea level standard conditions and 7,700 rpm. This engine is now installed in a wide variety of latest military aircraft.**



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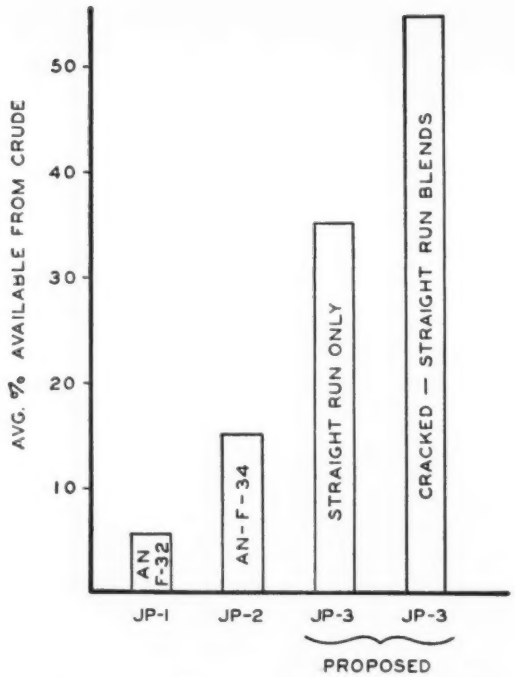



Figure 10 — Availability of various types of aircraft gas turbine fuels.

with cracked fuels are necessary to establish whether they are satisfactory from the standpoint of stability.

## Freezing Point

Low temperature characteristics of jet fuels are particularly important in military service. The freezing point of −76° F. maximum in the present JP-1 grade (AN-F-32*) of jet fuel and the JP-3 grade (AN-F-58*) was obviously inherited from former aviation gasoline specifications. Comparatively little information is available indicating the maximum allowable freezing point based on actual test data of aircraft fuel systems, and this is believed necessary before final conclusions can be reached. Some work is now under way to study the effect of freezing point and cloud point on the pumpability of such fuels in aircraft fuel systems being tested in the cold room.

In addition to freezing point and cloud point of fuels, there is also a third factor, formation of ice crystals which affects the low temperature behavior of fuels. At certain temperatures fuels may contain up to 0.015% by weight of water dissolved in the fuel. As the fuel temperature is reduced, its water solubility is also reduced, causing precipitation of water and finally the formation of ice crystals. These data show approximately the same degree of water solubility of aviation gasoline and kerosine. In military operation the low freezing point of jet fuel is believed desirable, although in commercial service some compromise may be made in the interest of reduction of fire hazard and fuel cost.

*Copies may be obtained from Commanding General, Air Materiel Command, Wright Field, Dayton, O.

## Availability

An industry-wide study has been under way to determine the quantities of such fuels which could be made available in the event of a national emergency. This study has included a variety of crudes actually produced in this country. Two conditions which were made were: (1) first priority was given to jet fuel production; (2) existing refinery equipment would be utilized. By operating the refineries to produce the maximum quantity of each grade, the amounts which can be made available appear on Figure 10. JP-1 grade of fuel is now required for all flight and ground operations of military aircraft. The quantity of this grade, essentially kerosine, which can be made available is approximately 6%, which is relatively low. Freezing point and viscosity requirements appear to be the most restrictive requirements.

Until recently grade JP-2, AN-F-34, was indicated for ground testing of jet engines. It has since become obsolete. The quantity of this grade which can be made available is approximately 15%. Although the distillation range is wider than permitted in the JP-1 grade, other requirements of the specifications do not permit taking full advantage and hence the available quantity falls short of expectations for emergency requirements.

Specifications for a third grade, JP-3, have been released and it is expected to ultimately replace grade

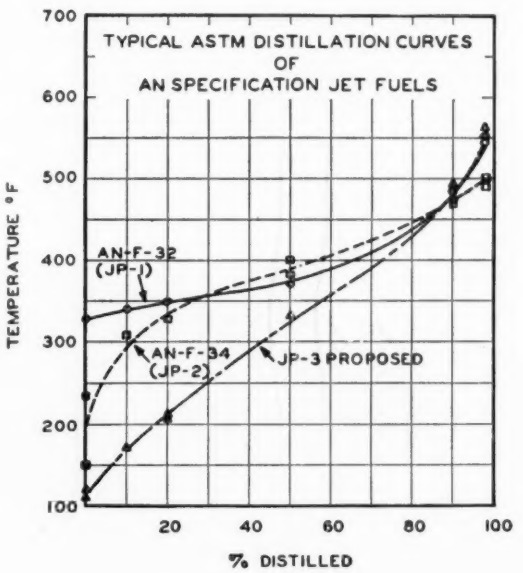


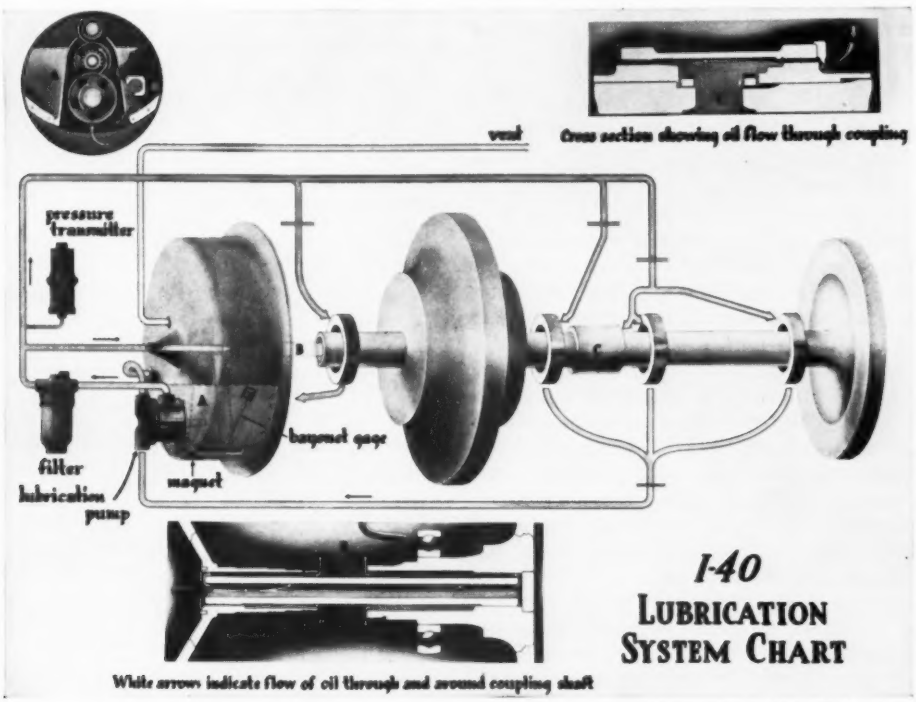

Figure 11

JP-1. The principal change from the JP-1 to the JP-3 grade is a much wider distillation range which has been increased to approximately 100 to 600° F. (Figure 11) and a Reid Vapor Pressure of 5 to 7 pounds. The quantity of the proposed JP-3 fuel which might be made available from straight run stocks is only approximately 30 to 35%, or if cracked stocks can be utilized this quantity might increase to approximately 55%. The JP-3 grade based upon data already obtained should show satisfactory performance in the engine from the standpoint of good low temperature starting, combustion efficiency, smoke and deposits.

The lubrication requirements imposed by the aircraft are generally applicable to all types of aircraft gas turbines whether they be turbojets, propjets, ducted fans, or combination of these types and are made up from the following:

### Altitude Requirements

A modern turbine powered aircraft will operate at all altitudes of from sea level to 40-50,000 feet or higher. Over this altitude range, the atmospheric pressure will vary from 14.7 p.s.i. absolute at sea level to 1.68 p.s.i. absolute at 50,000 feet. Over this pressure range, the lubricating oil of the




*Courtesy General Electric Company*

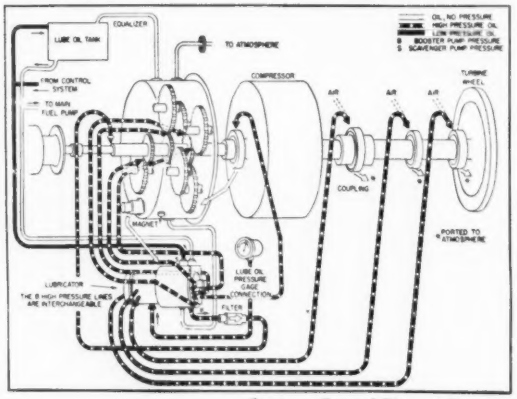
Figure 12 — A schematic diagram of lubrication system of J-33 General Electric I-40 turbojet engine.

## LUBRICATION OF AIRCRAFT GAS TURBINES

The lubrication requirements of the aircraft gas turbine are imposed by two factors. The first of these is the turbine which requires that the lubricant lubricate the bearings and various other moving parts of the turbine under static sea level conditions.

The second is the aircraft which requires that the lubricant maintain satisfactory lubrication at all of the speeds, altitudes, and geographical locations to which the aircraft will subject the turbine. Generally, the lubrication requirements of the turbine can be easily satisfied, while those imposed by the aircraft are much more severe and difficult to meet. turbine must show no tendency to foam or to lose an excessive amount of light ends due to evaporation. Also, over this altitude range, the ambient temperature may vary from +160° F. at sea level on a desert hot day to less than —80° F. at high altitudes. Under these extremes of temperature, the lubricating oil must be stable, resistant to oxidation, and permit easy starting. Unlike conventional reciprocating power plants where cold starting problems are primarily confined to starting the engine on the ground, the aircraft gas turbine presents a problem of restarting in flight at high altitudes.

Because it is characteristic of the turbine to obtain maximum efficiency at or near maximum power, it is probable that very large aircraft of the future




*Courtesy General Electric Company*

**Figure 13 – A schematic diagram of lubrication system J-35 General Electric TG-180 turbojet engine.**

employing a number of turbine power plants will find it more economical to operate only a few of the total number of turbines available when cruising at reduced power on long range flights. The non-operative turbine units will thus be exposed to low temperatures for extended periods, after which they must be restarted prior to landing. Such an operation imposes a very severe cold starting requirement on the lubricating oil since soaking temperatures may be as low as —80 to —90° F. Although there may be ways of reducing the magnitude of the low temperature soaking effect through the use of oil tank heaters, more favorable location of the oil tank by changing aircraft design, etc., usually such changes are accomplished only at the expense of overall aircraft performance and in no way lessen the basic requirement that the lubricating oil permit starting at very low temperatures.

Also affected by the extremes in temperature and pressure encountered in the high altitude – low altitude operation of aircraft gas turbines is the operation of engine accessory items which are normally lubricated and actuated by engine oil. These items include engine speed controls, propeller controls, and other related mechanisms. Although these mechanisms are not part of the turbine proper, they are necessary for satisfactory use of the turbine in aircraft and it is very desirable that these devices operate satisfactorily on the lubricating oil used in the turbine. The aeration and foaming characteristics of the lubricating oils under reduced pressures at high altitudes are very important.

## Speed Requirements

Speeds of present jet powered aircraft are beginning to enter the region where a temperature rise is encountered due to air compressibility. At a sustained speed of 600 mph the temperature rise is 64° F., at 800 mph—114° F. and at 1,000 mph—200° F.

As speeds are increased in the future this temperature rise due to compressibility of air may introduce a problem with respect to oil cooling and make it more difficult to reject engine heat.

## Climatic Requirements

The requirement for an aircraft to be able to take-off from one part of the world and land on another part of the world having a completely different climate is generally overlooked. The ability of an aircraft to span great distances imposes certain requirements on the lubricating oil. In cold climates, the lubricating oil must permit quick and easy starting. In tropical climates, the lubricating oil must be stable and because tropical climates are usually very humid, the lubricating oil must inhibit against rust and corrosion. In other words, the aircraft gas turbine imposes the requirement that a lubricating oil be suitable under all of the climatic conditions found anywhere in the world.

## The Types Involved

From the lubrication viewpoint, present day aircraft gas turbines may be divided into two groups.

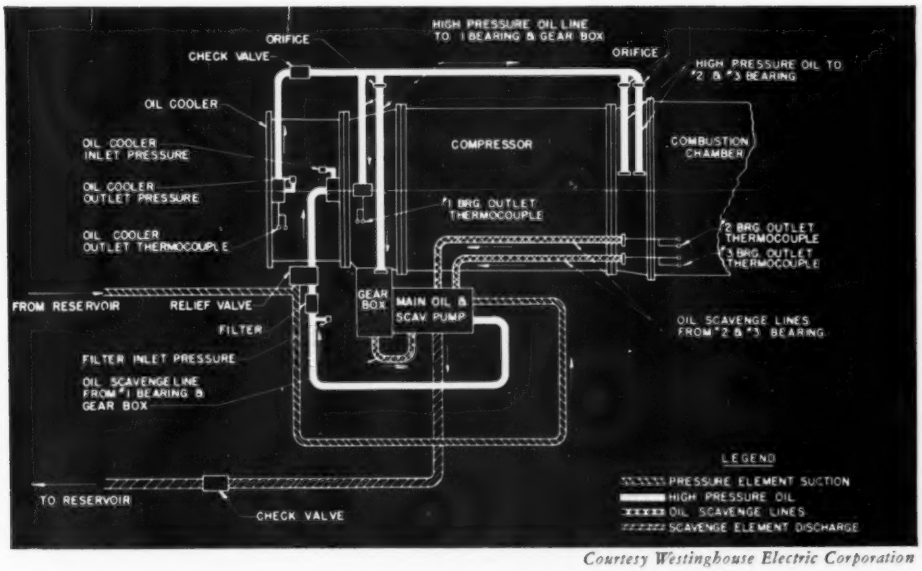
Group I—The turbojets which will operate satisfactorily on light lubricating oils.

Group II—The propjets which require higher viscosity oils for lubrication of highly loaded propeller reduction gears.

Other types of aircraft gas turbines such as the ducted fan arrangement are not included in this discussion because these types have not been developed in the U. S.

The turbojets are comparatively easy to lubricate. This results from their simple construction and absence of large numbers of moving parts. It will be noted from the schematic lubrication diagram (Figure 12) that the J-33 (I-40) turbojet engine delivers oil under pressure to four main ball and roller bearings, a coupling on the main shaft, the quill shaft splines of the accessory drive and gears and bearings in the accessory case. Oil from the front main bearing and accessory shaft drains into the oil reservoir in the accessory case. Oil from the other parts is returned by a scavenger pump. The J-33 will operate satisfactorily on a wide variety of oils, but because of starting requirements, a very light oil conforming to Spec. AN-0-9, grade 1010 is used.

The J-35 (TG-180) turbojet engine (Figure 9) differs considerably from the J-33 (I-40) in that it employs an axial flow compressor instead of a centrifugal compressor. The J-35 lubrication system (Figure 13) is also different and employs a combination of solid oil jet for the engine forward end and an air-oil mist lubrication for the aft three bearings. A multi-plunger lubricator or piston type



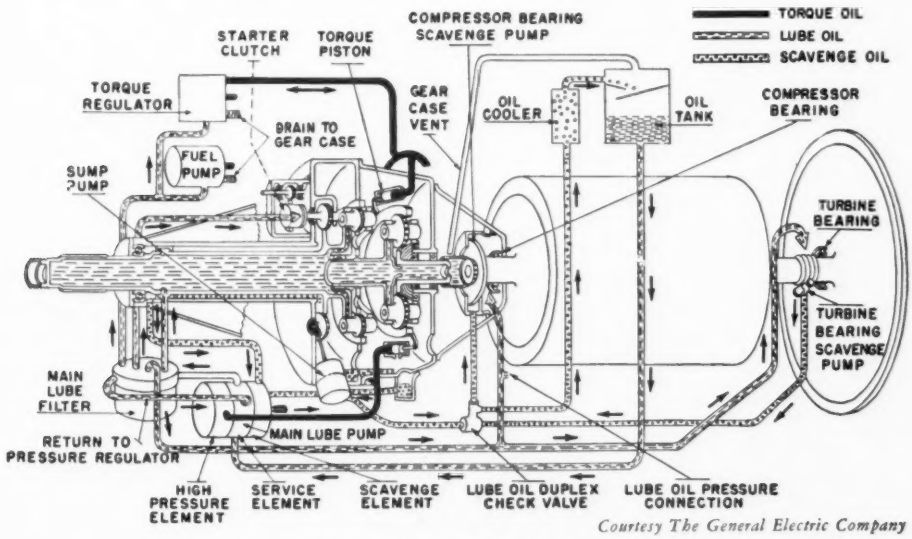

*Courtesy Westinghouse Electric Corporation*

Figure 14 — Lubrication system diagram of the Westinghouse J-30WE-20 turbojet engine.

pump delivers a separate jet each to front main bearing and accessory drive gears. Oil drained from the bearings and gears in the front section is scavenged and returned to the tank. For each of the other three main bearings a separate metered supply of oil is delivered or atomized with air taken from the fourth stage of the compressor. This air-oil mixture is finally discharged overboard. Since a major part of the heat rejected to the oil is carried overboard no oil cooler is required.

Until recently the J-35 (TG-180) engine required specification AN-0-8, Grade 1065 oil. With recent changes in design a lower viscosity oil meeting specification AN-0-9, grade 1010 may be used successfully.

The Westinghouse J-30 and J-34 turbojets differ considerably from the G.E. J-33 and J-35 units from the lubrication viewpoint. Whereas, the J-33 and J-35 turbojets utilize ball and roller bearings on the main rotor shaft the Westinghouse J-30 and J-34 employ sleeve bearings at these locations. A diagramatic lubrication system of the J-30WE-20 is shown in Figure 14. During operation of the engine, the main pump draws oil from the reservoir,




*Courtesy The General Electric Company*

Figure 15 — Lubrication System of the T-35 Turbo-Prop (G. E. Model TG-100)



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**TABLE II**

Typical Tests of Aircraft Gas Turbine Lubricating Oils

| | AN-0-9 Grade 1010 | AN-0-8 Grade 1065 |
|---|---|---|
| Flash, C.O.C., °F. | 300 | 460 |
| Fire, C.O.C., °F. | 335 | 520 |
| Pour °F. | −70 | 0 |
| Viscosity, S.U.S. | | |
| at −40° F. | 12936 | ... |
| 100 | 59.4 | 530 |
| 210 | 34.5 | 67 |
| Viscosity Index | 66 | 103 |
| Sulfur, % | 0.05 | 0.15 |
| Neut. No. | 0.02 | 0.01 |
| Carbon Residue % | 0.02 | 0.14 |
| Ash | None | None |
| Corrosion | | |
| Cu, Fe, Al, Mg | OK | ... |

pumps it through a filter, relief valve, cooler and then into the bearings and gear box. Oil is returned to the reservoir by a scavenger pump. The front and rear main bearings are of the sleeve type and carry radial loads only while the mid-main bearing carries both radial and thrust loads. The J-34 is similar to the J-30 only much larger. Both the J-30 and the J-34 turbojets will operate satisfactorily using Spec. AN-0-9, grade 1010, lubricating oil.

In the second group of aircraft gas turbines are the turboprops. A typical turboprop is the T-35 General Electric (TG-100), see lubrication diagram Figure 15. In the T-35, the main rotor shaft not only operates the compressor and turbine wheel, but also drives the propeller through a planetary reduction gear. Because the reduction gear design was based on conventional aircraft gear practice, the reduction gear has required the use of aircraft engine oils such as, Spec. AN-0-8, grade 1065, lubricating oil.

The use of grade 1065 lubricating oil although satisfactory under operating conditions presents a low temperature starting problem. Because of the aircraft imposed starting requirements of —65° F., reduction gears and lubricating oils must be developed which will be mutually compatible under both operating and starting conditions.

The lubricating oils which have been used in turbojets have progressed chronologically from the aircraft type hydraulic oils to a highly refined straight petroleum oil exhibiting an extremely low pour point. The use of aircraft hydraulic oil was abandoned in some of the turbojets because this oil was unsuitable. However, now all turbojet operation has been standardized on petroleum oils conforming to Spec. AN-0-9, grade 1010. In Table II are shown the pertinent physical and chemical properties of this oil. The lubricating oils used in the turboprops have been of the aircraft engine oil type conforming to Spec. AN-0-8. To date, the trend has been to adopt the grade 1065. Pertinent data on this oil is also shown in Table II.

## SUMMARY

The selection of fuel for the aircraft gas turbine requires a careful consideration of engine design, operating conditions and type of service. For military service the type of fuel now proposed as JP-3 grade will have a wide boiling range of 100°-600° F. Its advantages will be good combustion efficiency, easy starting at low temperatures, low freezing point and availability in large quantities.

For commercial service the requirements may differ in that there is a preference for a low volatility fuel such as JP-1 grade or commercial kerosine for reasons of reduced fire hazard. This type of fuel has the principal disadvantage, however, of lack of availability in large quantities and to a lesser degree starting is more difficult at extremely low temperatures. The above advantage plus greater heating value per gallon and less vapor locking and evaporation tendencies may offset the disadvantages to favor its selection for this service. In either military or commercial service it is doubtful whether present jet engines will be able to utilize heavier distillate fuels such as Diesel fuel.

The selection of lubricating oils for the aircraft gas turbine may be divided into two classes, (1) turbojet and (2) propjet. In the turbojet engine the extremely low starting temperature and the moderately low operating temperature, favor the selection of a low viscosity lubricating oil. This type of oil also is satisfactory for the gears and bearings where the loads are rather light.

Propjet engines on the other hand, present a greater problem. In these engines a lubricant must be selected to meet the requirements of highly loaded reduction gears and still have a low enough viscosity to permit satisfactory starting at the lowest anticipated temperatures. Much work remains to be done in this field before the best combination of engine design and lubricating oil is found.

## References

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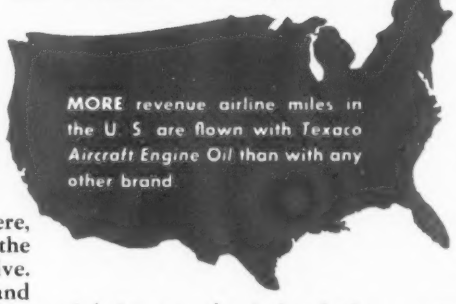


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